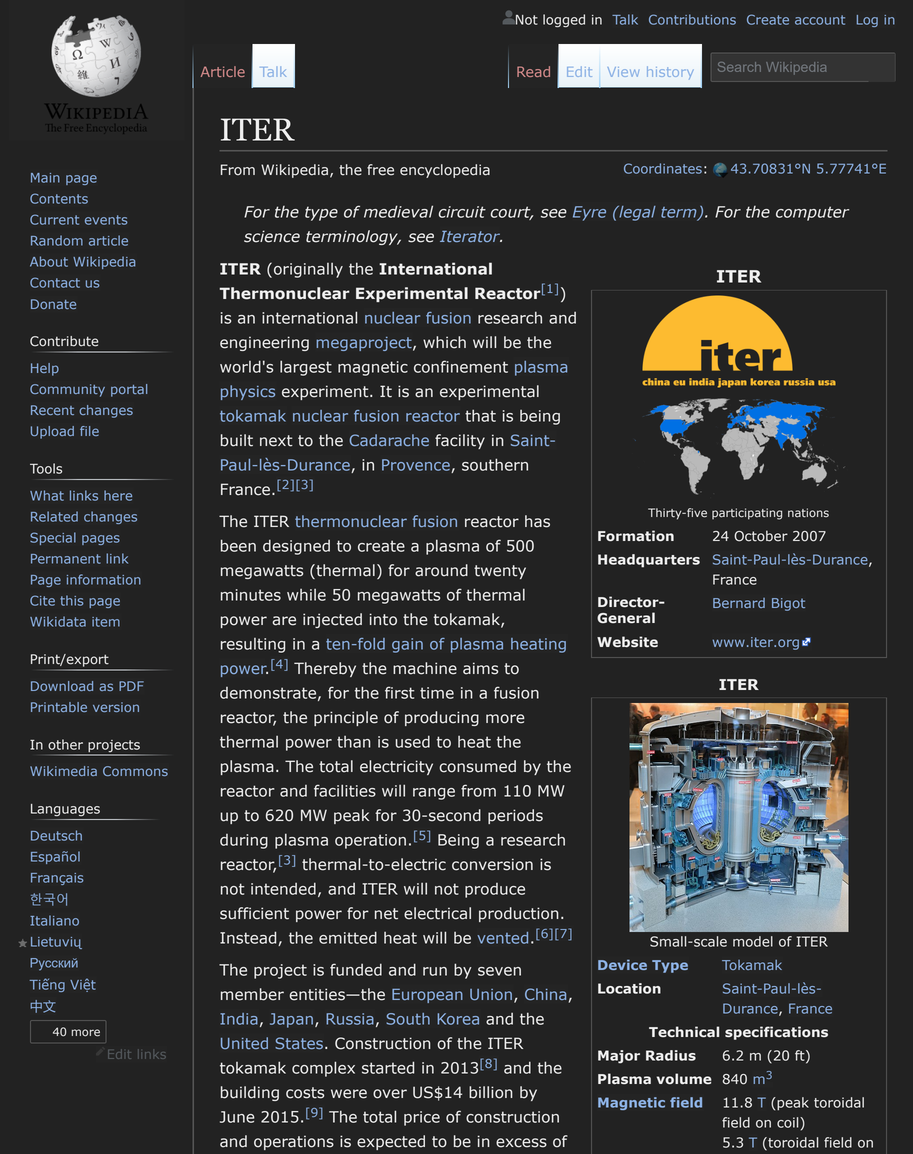

ITER

From Wikipedia, the free encyclopedia

Coordinates: 43.70831°N 5.77741°E

For the type of medieval circuit court, see Eyre (legal term). For the computer science terminology, see Iterator.

ITER (originally the **International Thermonuclear Experimental Reactor**[1]) is an international nuclear fusion research and engineering megaproject, which will be the world's largest magnetic confinement plasma physics experiment. It is an experimental tokamak nuclear fusion reactor that is being built next to the Cadarache facility in Saint-Paul-lès-Durance, in Provence, southern France.[2][3]

The ITER thermonuclear fusion reactor has been designed to create a plasma of 500 megawatts (thermal) for around twenty minutes while 50 megawatts of thermal power are injected into the tokamak, resulting in a ten-fold gain of plasma heating power.[4] Thereby the machine aims to demonstrate, for the first time in a fusion reactor, the principle of producing more thermal power than is used to heat the plasma. The total electricity consumed by the reactor and facilities will range from 110 MW up to 620 MW peak for 30-second periods during plasma operation.[5] Being a research reactor,[3] thermal-to-electric conversion is not intended, and ITER will not produce sufficient power for net electrical production. Instead, the emitted heat will be vented.[6][7]

The project is funded and run by seven member entities—the European Union, China, India, Japan, Russia, South Korea and the United States. Construction of the ITER tokamak complex started in 2013[8] and the building costs were over US$14 billion by June 2015.[9] The total price of construction and operations is expected to be in excess of

ITER

Thirty-five participating nations

Formation	24 October 2007
Headquarters	Saint-Paul-lès-Durance, France
Director-General	Bernard Bigot
Website	www.iter.org

ITER

Small-scale model of ITER

Device Type	Tokamak
Location	Saint-Paul-lès-Durance, France

Technical specifications

Major Radius	6.2 m (20 ft)
Plasma volume	840 m^3
Magnetic field	11.8 T (peak toroidal field on coil) 5.3 T (toroidal field on

€20 billion.[10] The US Department of Energy has estimated the total construction costs to 2025 to be $65 billion. [11] Overall, 35 countries are participating in the project directly or indirectly. The objectives of the ITER project include bootstrapping the global nuclear fusion industry.[3]

The goal of ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful use.[12] It is the largest of more than 100 fusion reactors built since the 1950s.[12] ITER's planned successor, DEMO, which for some ITER consortium countries may now be a phase rather than a specific ITER consortium machine, is expected to be the first fusion reactor to produce electricity in an experimental environment. The DEMO phase is expected to lead to full-scale electricity-producing fusion power stations and future commercial reactors.[13]

	axis) 6 T (peak poloidal field on coil)
Heating power	50 MW
Fusion power	500 MW
Discharge duration	up to 1000 s
History	
Date(s) of construction	2013 – 2025

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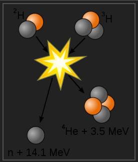
Background [edit]



ITER will produce energy by fusing deuterium and tritium to helium.

Fusion power has the potential to provide sufficient energy to satisfy mounting demand, and to do so sustainably, with a relatively small impact on the environment. 1 gram of deuterium-tritium mixture in the process of nuclear fusion produces an amount of energy equivalent to burning 80,000 tonnes of oil.[3] [disputed: may actually be 8 tonnes]

Nuclear fusion has many potential attractions. Firstly, its hydrogen isotope fuels are relatively abundant – one of the necessary isotopes, deuterium, can be extracted from seawater, while the other fuel, tritium, would be bred from a lithium blanket using neutrons produced in the fusion reaction itself.[14] Furthermore, a fusion reactor would produce virtually no CO_2 or atmospheric pollutants, and its radioactive waste products would mostly be very short-lived compared to those produced by conventional nuclear reactors (fission reactors).

On 21 November 2006, the seven participants formally agreed to fund the creation of a nuclear fusion reactor.[15] The program is anticipated to last for 30 years – 10 for construction, and 20 of operation. ITER was originally expected to cost approximately €5 billion, but the rising price of raw materials and changes to the initial design have seen that amount almost triple to €13 billion.[9] The reactor is expected to take 10 years to build with completion originally scheduled for 2019, but construction has continued into 2020.[16] Site preparation has begun in Cadarache, France, and procurement of large components has started.[17]

When supplied with 300 MW of electrical power, ITER is expected to produce the equivalent of 500 MW of thermal power sustained for up to 1,000 seconds[18] (this compares to JET's consumption of 700 MW of electrical power and peak thermal output of 16 MW for less than a second) by the fusion of about 0.5 g of deuterium/tritium mixture in its approximately 840 m^3 reactor chamber. The heat produced in ITER will not be used to generate any electricity because after accounting for losses and the 300 MW minimum power input, the output will be equivalent to a zero (net) power reactor.[6] If operated continuously and connected to the electric grid, its 500 MW thermal output would translate to about 200 megawatts of electric power, enough for about 200,000 homes. [19]

Organization history [edit]

Ronald Reagan and Mikhail Gorbachev at the Geneva Summit in 1985

ITER began in 1985 as a Reagan–Gorbachev[20][21] initiative[21][22] with the equal participation of the Soviet Union, the European Atomic Energy Community, the United States, and Japan through the 1988–1998 initial design phases. Preparations for the first Gorbachev-Reagan Summit showed that there were no tangible agreements in the works for the summit.

One energy research project, however, was being considered quietly by two physicists, Alvin Trivelpiece and Evgeny Velikhov. The project involved collaboration on the next phase of magnetic fusion research — the construction of a demonstration model. At the time, magnetic fusion research was ongoing in Japan, Europe, the Soviet Union and the US. Velikhov and Trivelpiece believed that taking the next step in fusion research would be beyond the budget of any of the key nations and that collaboration would be useful internationally.

A major bureaucratic fight erupted in the US government over the project. One argument against collaboration was that the Soviets would use it to steal US technology and know-how. A second was symbolic — the Soviet physicist Andrei Sakharov was in internal exile and the US was pushing the Soviet Union on its human rights record. The United States National Security Council convened a meeting under the direction of William Flynn Martin that resulted in a consensus that the US should go forward with the project.

Martin and Velikhov concluded the agreement that was agreed at the summit and announced in the last paragraph of this historic summit meeting, "... The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentially inexhaustible, for the benefit for all mankind."[23]

Conceptual and engineering design phases carried out under the auspices of the IAEA led to an acceptable, detailed design in 2001, underpinned by US$650 million worth of research and development by the "ITER Parties" to establish its practical feasibility.[*citation needed*] These parties, namely EU, Japan, Russian Federation (replacing the Soviet Union), and United States (which opted out of the project in 1999 and returned in 2003), were joined in negotiations by China, South Korea, and Canada (who then terminated its participation at the end of 2003). India officially became part of ITER in December 2005.

On 28 June 2005, it was officially announced that ITER would be built in the European Union in Southern France. The negotiations that led to the decision ended in a compromise between the EU and Japan, in that Japan was promised 20% of the research staff on the French location of ITER, as well as the head of the administrative body of ITER. In addition, another research facility for the project will be built in Japan, and the European Union has agreed to contribute about 50% of the costs of this institution.[24]

On 21 November 2006, an international consortium signed a formal agreement to build the reactor.[25] On 24 September 2007, the People's Republic of China became the seventh party to deposit the ITER Agreement to the IAEA. Finally, on 24 October 2007, the ITER Agreement entered into force and the ITER Organization legally came into existence.

In 2016 the ITER organization signed a technical cooperation agreement with the national nuclear fusion agency of Australia, granting this country access to research results of ITER in exchange for construction of selected parts of the ITER machine.[26]

The project began its five-year assembly phase in July 2020, launched by the French president, Emmanuel Macron in the presence of other members of the ITER project.[27]

Directors-General [edit]

The project has had three Directors-General. The Director-General reports to the ITER Council, which is composed of two representatives from each of the domestic agencies. The ITER organization does not publicly disclose the names of the Council members.[28]

2005-2010: Kaname Ikeda
2010-2014: Osamu Motojima

2015-current: Bernard Bigot

Objectives [edit]

ITER's mission is to demonstrate the feasibility of fusion power, and prove that it can work without negative impact.[29] Specifically, the project aims to:

- Momentarily produce a fusion plasma with thermal power ten times greater than the injected thermal power (a *Q* value of 10).
- Produce a steady-state plasma with a *Q* value greater than 5. (*Q* = 1 is scientific breakeven.)
- Maintain a fusion pulse for up to 8 minutes.
- Develop technologies and processes needed for a fusion power station — including superconducting magnets and remote handling (maintenance by robot).
- Verify tritium breeding concepts.
- Refine neutron shield/heat conversion technology (most of the energy in the D+T fusion reaction is released in the form of fast neutrons).

The objectives of the ITER project are not limited to creating the nuclear fusion device but much broader, including building necessary technical, organizational and logistical capabilities, skills, tools, supply chains and culture enabling management of such megaprojects among participating countries, bootstrapping their local nuclear fusion industries.[3]

Timeline and status [edit]

Aerial view of the ITER site in 2018

ITER construction status in 2018

In 1978, the European Commission, Japan, United States, and USSR joined in the International Tokamak Reactor (INTOR) Workshop, under the auspices of the International Atomic Energy Agency (IAEA), to assess the readiness of magnetic fusion to move forward to the experimental power reactor (EPR) stage, to identify the additional R&D that must be undertaken, and to define the characteristics of such an EPR by means of a conceptual design. Hundreds of fusion scientists and engineers in each participating country took part in a detailed assessment of the then present status of the tokamak confinement concept vis-a-vis the requirements of an EPR, identified the required R&D by early 1980, and produced a conceptual design by mid-1981.

In 1985, at the Geneva summit meeting in 1985, Mikhail Gorbachev suggested to Ronald Reagan that the two countries jointly undertake the construction of a tokamak EPR as proposed by the INTOR Workshop. The ITER project was initiated in 1988.[30][31]

Construction of the ITER tokamak complex started in 2013.[8] Machine assembly was launched on 28 July 2020.[32] The construction of the facility is expected to be completed in 2025 when commissioning of the reactor can commence. Initial plasma experiments are scheduled to begin in 2025, with full deuterium–tritium fusion experiments starting in 2035.[33][34] If ITER becomes operational, it will become the largest magnetic confinement plasma physics experiment in use with a plasma volume of 840 cubic meters,[35] surpassing the Joint European Torus by a factor of 8.

Project milestones

Date	Event
1988	ITER project officially initiated.[30][31] Conceptual design activities ran from 1988 to 1990.[36]
1992	Engineering design activities from 1992[37] to 1998.[38]
2006	Approval of a cost estimate of €10 billion (US$12.8 billion) projecting the start of construction in 2008 and completion a decade later.[15]
2008	Site preparation start, ITER itinerary start.[39]
2009	Site preparation completion.[39]
2010	Tokamak complex excavation starts.[31]
2013	Tokamak complex construction starts.[39]
2015	Tokamak construction starts,[40][41] but the schedule is extended by at least six years.[42]
2017	Assembly Hall ready for equipment.
2018-2025	Assembly and integration:[43] December 2018: Concrete support finished.[44] July 2019: Bottom and lower cylinder of the cryostat assembled from pieces.[45] May 2020: Bottom of the cryostat installed, tokamak assembly started.[46] July 2020: Machine assembly formally launched.[32] November 2020 (planned): Start welding vacuum vessel together.[47] June 2022 (planned): Vacuum vessel installed.[48] November 2023 (planned): Installation of central solenoid starts.[49]
2025	Planned: Assembly ends; commissioning phase starts.[43] Planned: Achievement of first plasma.[50]
2035	Planned: Start of deuterium–tritium operation.[51]

Reactor overview [edit]

See also: Nuclear fusion

When deuterium and tritium fuse, two nuclei come together to form a helium nucleus (an alpha particle), and a high-energy neutron.

$${}^{2}_{1}\mathrm{D} + {}^{3}_{1}\mathrm{T} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + 17.59\ \mathrm{MeV}$$

While nearly all stable isotopes lighter on the periodic table than iron-56 and nickel-62, which have the highest binding energy per nucleon, will fuse with some other isotope and release energy, deuterium and tritium are by far the most attractive for energy generation as they require the lowest activation energy (thus lowest temperature) to do so, while producing among the most energy per unit weight.

All proto- and mid-life stars radiate enormous amounts of energy generated by fusion processes. Mass for mass, the deuterium–tritium fusion process releases roughly three times as much energy as uranium-235 fission, and millions of times more energy than a chemical reaction such as the burning of coal. It is the goal of a fusion power station to harness this energy to produce electricity.

Activation energies (in most fusion systems this is the temperature required to initiate the reaction) for fusion reactions are generally high because the protons in each nucleus will tend to strongly repel one another, as they each have the same positive charge. A heuristic for estimating reaction rates is that nuclei must be able to get within 100 femtometers (1×10^{-13} meter) of each other, where the nuclei are increasingly likely to undergo quantum tunneling past the electrostatic barrier and the turning point where the strong nuclear force and the electrostatic force are equally balanced, allowing them to fuse. In ITER, this distance of approach is made possible by high temperatures and magnetic confinement. ITER uses cooling equipment like a cryopump to cool the magnets to close to absolute zero. High temperatures give the nuclei enough energy to overcome their electrostatic repulsion (see Maxwell–Boltzmann distribution). For deuterium and tritium, the optimal reaction rates occur at temperatures on the order of 100,000,000 K. The plasma is heated to a high temperature by ohmic heating (running a current through the plasma). Additional heating is applied using neutral beam injection (which cross magnetic field lines without a net deflection and will not cause a large electromagnetic disruption) and radio frequency (RF) or microwave heating.

At such high temperatures, particles have a large kinetic energy, and hence velocity. If unconfined, the particles will rapidly escape, taking the energy with them, cooling the plasma to the point where net energy is no longer produced. A successful reactor would need to contain the particles in a small enough volume for a long enough time for much of the plasma to fuse. In ITER and many other magnetic confinement reactors, the plasma, a gas of charged particles, is confined using magnetic fields. A charged particle moving through a magnetic field experiences a force perpendicular to the direction of travel, resulting in centripetal acceleration, thereby confining it to move in a circle or helix around the lines of magnetic flux.

A solid confinement vessel is also needed, both to shield the magnets and other equipment from high temperatures and energetic photons and particles, and to maintain a near-vacuum for the plasma to populate. The containment vessel is subjected to a barrage of very energetic particles, where electrons, ions, photons, alpha particles, and neutrons constantly bombard it and degrade the structure. The material must be designed to endure this environment so that a power station would be economical. Tests of such materials will be carried out both at ITER and at IFMIF (International Fusion Materials Irradiation Facility).

Once fusion has begun, high energy neutrons will radiate from the reactive regions of the plasma, crossing magnetic field lines easily due to charge neutrality (see neutron flux). Since it is the neutrons that receive the majority of the energy, they will be ITER's primary source of energy output. Ideally, alpha particles will expend their energy in the plasma, further heating it.

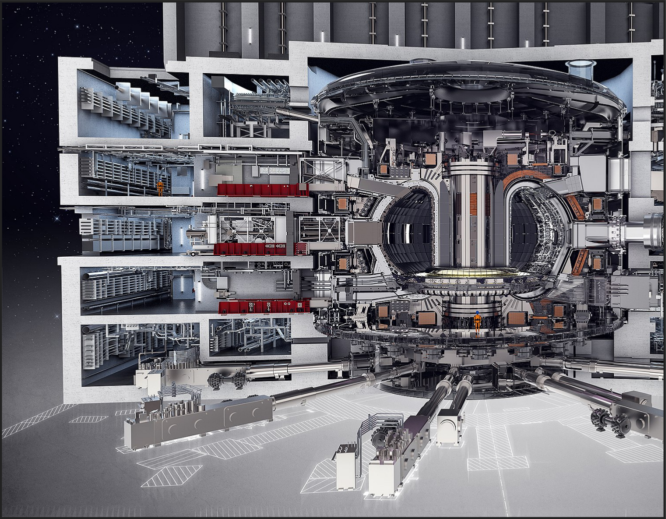
Beyond the inner wall of the containment vessel one of several test blanket modules will be placed. These are designed to slow and absorb neutrons in a reliable and efficient manner, limiting damage to the rest of the structure, and breeding tritium for fuel from lithium-bearing ceramic pebbles contained within the blanket module following the following reactions:

$$ {}^{1}_{0}\mathrm{n} + {}^{6}_{3}\mathrm{Li} \rightarrow {}^{3}_{1}\mathrm{T} + {}^{4}_{2}\mathrm{He} $$
$$ {}^{1}_{0}\mathrm{n} + {}^{7}_{3}\mathrm{Li} \rightarrow {}^{3}_{1}\mathrm{T} + {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} $$

where the reactant neutron is supplied by the D-T fusion reaction.

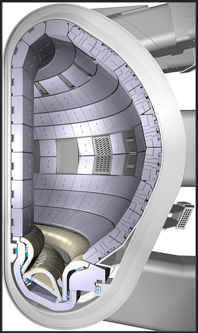
Energy absorbed from the fast neutrons is extracted and passed into the primary coolant. This heat energy would then be used to power an electricity-generating turbine in a real power station; in ITER this generating system is not of scientific interest, so instead the heat will be extracted and disposed of.

Technical design [edit]



Drawing of the ITER tokamak and integrated plant systems

Vacuum vessel [edit]

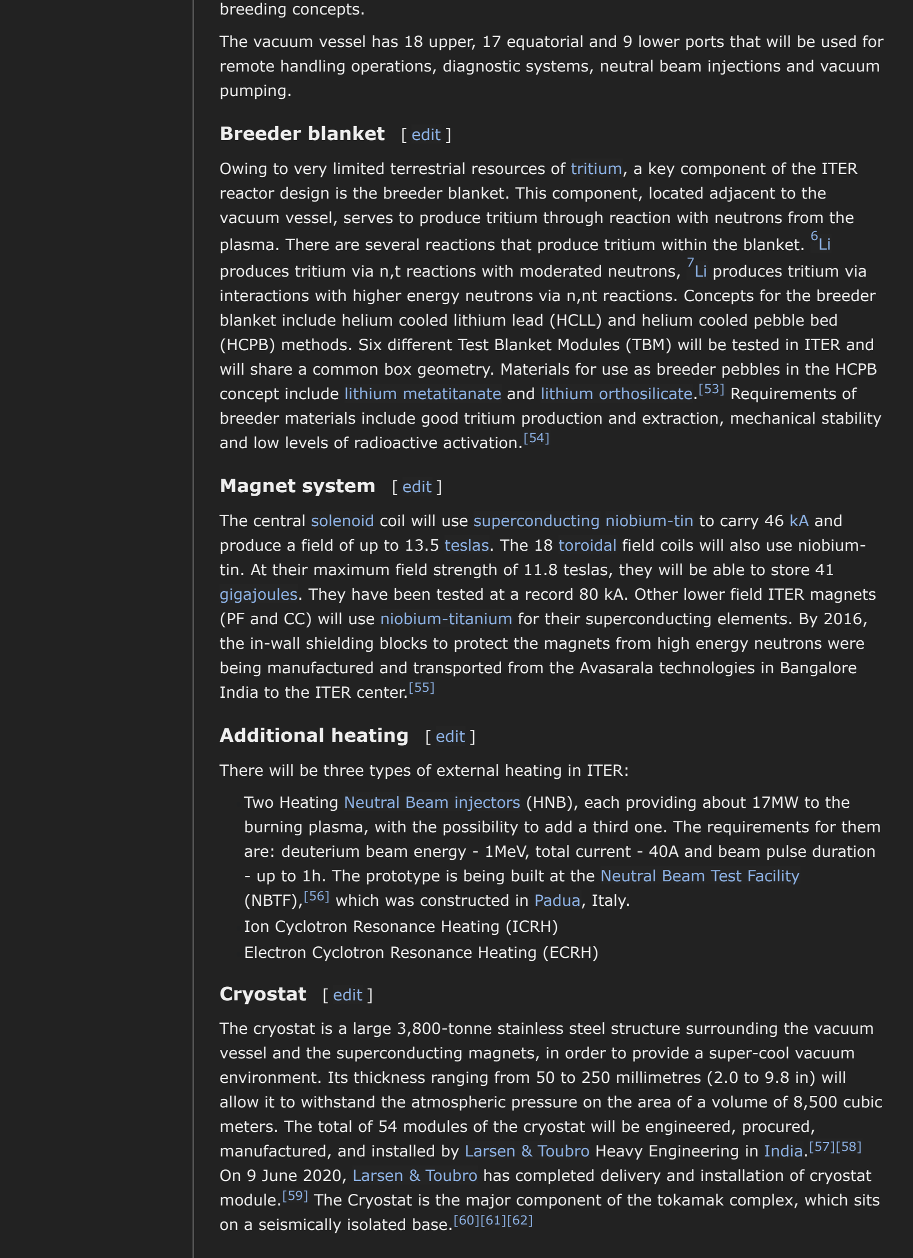


Cross-section of part of the planned ITER fusion reaction vessel.

The vacuum vessel is the central part of the ITER machine: a double walled steel container in which the plasma is contained by means of magnetic fields.

The ITER vacuum vessel will be twice as large and 16 times as heavy as any previously manufactured fusion vessel: each of the nine torus-shaped sectors will weigh between 390 and 430 tonnes.[52] When all the shielding and port structures are included, this adds up to a total of 5,116 tonnes. Its external diameter will measure 19.4 metres (64 ft), the internal 6.5 metres (21 ft). Once assembled, the whole structure will be 11.3 metres (37 ft) high.

The primary function of the vacuum vessel is to provide a hermetically sealed plasma container. Its main components are the main vessel, the port structures and the supporting system. The main vessel is a double walled structure with poloidal and toroidal stiffening ribs between 60-millimetre-thick (2.4 in) shells to reinforce the vessel structure. These ribs also form the flow passages for the cooling water. The space between the double walls will be filled with shield structures made of stainless steel. The inner surfaces of the vessel will act as the interface with breeder modules containing the breeder blanket component. These modules will provide shielding from the high-energy neutrons produced by the fusion reactions and some will also be used for tritium



breeding concepts.

The vacuum vessel has 18 upper, 17 equatorial and 9 lower ports that will be used for remote handling operations, diagnostic systems, neutral beam injections and vacuum pumping.

Breeder blanket [edit]

Owing to very limited terrestrial resources of tritium, a key component of the ITER reactor design is the breeder blanket. This component, located adjacent to the vacuum vessel, serves to produce tritium through reaction with neutrons from the plasma. There are several reactions that produce tritium within the blanket. ^{6}Li produces tritium via n,t reactions with moderated neutrons, ^{7}Li produces tritium via interactions with higher energy neutrons via n,nt reactions. Concepts for the breeder blanket include helium cooled lithium lead (HCLL) and helium cooled pebble bed (HCPB) methods. Six different Test Blanket Modules (TBM) will be tested in ITER and will share a common box geometry. Materials for use as breeder pebbles in the HCPB concept include lithium metatitanate and lithium orthosilicate.[53] Requirements of breeder materials include good tritium production and extraction, mechanical stability and low levels of radioactive activation.[54]

Magnet system [edit]

The central solenoid coil will use superconducting niobium-tin to carry 46 kA and produce a field of up to 13.5 teslas. The 18 toroidal field coils will also use niobium-tin. At their maximum field strength of 11.8 teslas, they will be able to store 41 gigajoules. They have been tested at a record 80 kA. Other lower field ITER magnets (PF and CC) will use niobium-titanium for their superconducting elements. By 2016, the in-wall shielding blocks to protect the magnets from high energy neutrons were being manufactured and transported from the Avasarala technologies in Bangalore India to the ITER center.[55]

Additional heating [edit]

There will be three types of external heating in ITER:

> Two Heating Neutral Beam injectors (HNB), each providing about 17MW to the burning plasma, with the possibility to add a third one. The requirements for them are: deuterium beam energy - 1MeV, total current - 40A and beam pulse duration - up to 1h. The prototype is being built at the Neutral Beam Test Facility (NBTF),[56] which was constructed in Padua, Italy.
>
> Ion Cyclotron Resonance Heating (ICRH)
>
> Electron Cyclotron Resonance Heating (ECRH)

Cryostat [edit]

The cryostat is a large 3,800-tonne stainless steel structure surrounding the vacuum vessel and the superconducting magnets, in order to provide a super-cool vacuum environment. Its thickness ranging from 50 to 250 millimetres (2.0 to 9.8 in) will allow it to withstand the atmospheric pressure on the area of a volume of 8,500 cubic meters. The total of 54 modules of the cryostat will be engineered, procured, manufactured, and installed by Larsen & Toubro Heavy Engineering in India.[57][58] On 9 June 2020, Larsen & Toubro has completed delivery and installation of cryostat module.[59] The Cryostat is the major component of the tokamak complex, which sits on a seismically isolated base.[60][61][62]

Cooling systems [edit]

The ITER tokamak will use three interconnected cooling systems. Most of the heat will be removed by a primary water cooling loop, itself cooled by water through a heat exchanger within the tokamak building's secondary confinement. The secondary cooling loop will be cooled by a larger complex, comprising a cooling tower, a 5 km (3.1 mi) pipeline supplying water from Canal de Provence, and basins that allow cooling water to be cooled and tested for chemical contamination and tritium before being released into the Durance River. This system will need to dissipate an average power of 450 MW during the tokamak's operation. A liquid nitrogen system will provide a further 1300 kW of cooling to 80 K (−193.2 °C; −315.7 °F), and a liquid helium system will provide 75 kW of cooling to 4.5 K (−268.65 °C; −451.57 °F). The liquid helium system will be designed, manufactured, installed and commissioned by Air Liquide in France.[63][64]

Location [edit]

The process of selecting a location for ITER was long and drawn out. The most likely sites were Cadarache in Provence-Alpes-Côte-d'Azur, France, and Rokkasho, Aomori, Japan. Additionally, Canada announced a bid for the site in Clarington in May 2001, but withdrew from the race in 2003. Spain also offered a site at Vandellòs on 17 April 2002, but the EU decided to concentrate its support solely behind the French site in late November 2003. From this point on, the choice was between France and Japan. On 3 May 2005, the EU and Japan agreed to a process which would settle their dispute by July.

UNITED KINGDOM
NETH.
Dunkerque
Lille
BEL.
GERMANY
English Channel
Cherbourg
Le Havre
Rouen
LUX.
Rhine
Brest
PARIS
Seine
Strasbourg
Nancy
Orléans
Tours
Dijon
Nantes
SWITZ.
AUS.
A L P S
Bay of Biscay
Lyon
Saint-Étienne
Mont Blanc
Grenoble
ITALY
Bordeaux
Rhône
Toulouse
Montpellier
Nice
MONACO
Marseille
Toulon
PYRENEES
AND.
Corsica (FR.)
SPAIN
Mediterranean Sea
0 100 200 km
0 100 200 mi

Location of Cadarache in France

At the final meeting in Moscow on 28 June 2005, the participating parties agreed to construct ITER at Cadarache in Provence-Alpes-Côte-d'Azur, France. Construction of the ITER complex began in 2007, while assembly of the tokamak itself was scheduled to begin in 2015.[17]

Fusion for Energy, the EU agency in charge of the European contribution to the project, is located in Barcelona, Spain. Fusion for Energy (F4E) is the European Union's Joint Undertaking for ITER and the Development of Fusion Energy. According to the agency's website:

> F4E is responsible for providing Europe's contribution to ITER, the world's largest scientific partnership that aims to demonstrate fusion as a viable and sustainable source of energy. [...] F4E also supports fusion research and development initiatives [...][65]

The ITER Neutral Beam Test Facility aimed at developing and optimizing the neutral beam injector prototype, is being constructed in Padova, Italy.[66] It will be the only ITER facility out of the site in Cadarache.

Most of the buildings at ITER will or have been clad in an alternating pattern of reflective stainless steel and grey laquered metal; this was done due to aesthetic reasons to blend the buildings with their surrounding environment and to aid with thermal insulation.[67]

Participants [edit]

Thirty-five countries participate in the ITER project.

Currently there are seven parties participating in the ITER program: the European Union (through the legally distinct organisation Euratom), China, India, Japan, Russia, South Korea, and the United States.[17] Canada was previously a full member, but has since pulled out due to a lack of funding from the federal government. The lack of funding also resulted in Canada withdrawing from its bid for the ITER site in 2003. The host member of the ITER project, and hence the member contributing most of the costs, is the EU.

In 2007, the ITER signed a Cooperation Agreement with Kazakhstan.[68][69] In March 2009, Switzerland, an associate member of Euratom since 1979, also ratified the country's accession to the European Domestic Agency Fusion for Energy as a third country member.[70] The United Kingdom formally withdrew from Euratom on 31 January 2020. Nevertheless, the UK communicated to ITER a desire to continue participating in the project, with the terms of a new relationship to be negotiated during the transitional period of the UK's withdrawal from the European Union.[71] The future of the Joint European Torus project, which is located in the UK, is also not certain. Some type of associate membership in Euratom is considered a likely scenario, possibly similar to Switzerland.[72][73] In 2016, ITER announced a partnership with Australia for "technical cooperation in areas of mutual benefit and interest", but without Australia becoming a full member.[74]

ITER's work is supervised by the ITER Council, which has the authority to appoint senior staff, amend regulations, decide on budgeting issues, and allow additional states or organizations to participate in ITER.[75] The current Chairman of the ITER Council is Won Namkung,[76] and the ITER Director-General is Bernard Bigot.

Members [edit]

- EU
- China
- India
- Japan
- Russia
- South Korea
- United States

Non-members [edit]

- Australia (through the Australian Nuclear Science and Technology Organisation (ANSTO) in 2016)[77]
- Kazakhstan (through Kazakhstan's National Nuclear Center in 2017)[77]
- Switzerland (through Fusion for Energy)[70]

Funding [edit]

As of 2016, the total price of constructing the experiment is expected to be in excess of €20 billion,[10] an increase of €4.6 billion of its 2010 estimate,[78] and of €9.6 billion from the 2009 estimate.[79] Prior to that, the proposed costs for ITER were €5 billion for the construction and €5 billion for maintenance and the research connected with it during its 35-year lifetime. At the June 2005 conference in Moscow the participating members of the ITER cooperation agreed on the following division of funding contributions: 45% by the hosting member, the European Union, and the rest split between the non-hosting members – China, India, Japan, South Korea, the Russian Federation and the USA.[80][81][82] During the operation and deactivation phases, Euratom will contribute to 34% of the total costs,[83] Japan and the United States 13 percent, and China, India, Korea, and Russia 10 percent.[84]

Ninety percent of contributions will be delivered "in-kind" using ITER's own currency, the ITER Units of Account (IUAs).[84] Although Japan's financial contribution as a non-hosting member is one-eleventh of the total, the EU agreed to grant it a special status so that Japan will provide for two-elevenths of the research staff at Cadarache and be awarded two-elevenths of the construction contracts, while the European Union's staff and construction components contributions will be cut from five-elevenths to four-elevenths.

It was reported in December 2010 that the European Parliament had refused to approve a plan by member states to reallocate €1.4 billion from the budget to cover a shortfall in ITER building costs in 2012–13. The closure of the 2010 budget required this financing plan to be revised, and the European Commission (EC) was forced to put forward an ITER budgetary resolution proposal in 2011.[85]

Criticism [edit]

www.stop-iter.org
STOP-ITER
OUI AUX ENERGIES RENOUVELABLES
Sortir du nucléaire, c'est possible !

Protest against ITER in France, 2009. Construction of the ITER facility began in 2007, but the project has run into many delays and budget overruns.[33] The World Nuclear Association says that fusion "presents so far insurmountable scientific and engineering challenges".[86]

A technical concern is that the 14 MeV neutrons produced by the fusion reactions will damage the materials from which the reactor is built.[87] Research is in progress to determine whether and how reactor walls can be designed to last long enough to make a commercial power station economically viable in the presence of the intense neutron bombardment. The damage is primarily caused by high energy neutrons knocking atoms out of their normal position in the crystal lattice. A related problem for a future commercial fusion power station is that the neutron bombardment will induce radioactivity in the reactor material itself.[88] Maintaining and decommissioning a commercial reactor may thus be difficult and expensive. Another problem is that superconducting magnets are damaged by neutron fluxes. A new special research facility, IFMIF, is planned to investigate this problem.

Another source of concern comes from the 2013 tokamak parameters database interpolation which says that power load on tokamak divertors will be five times the previously expected value for ITER and much more for actual electricity-generating reactors. Given that the projected power load on the ITER divertor is already very high, these new findings mean that new divertor designs should be urgently tested.[89] However, the corresponding test facility (ADX) has not received any funding as of 2018.

A number of fusion researchers working on non-tokamak systems, such as Robert Bussard and Eric Lerner, have been critical of ITER for diverting funding from what they believe could be a potentially more viable and/or cost-effective path to fusion power, such as the polywell reactor though the latter was ultimately found to be infeasible.[90][91][92] Many critics accuse ITER researchers of being unwilling to face up to the technical and economic potential problems posed by tokamak fusion schemes.[90] The expected cost of ITER has risen from US$5 billion to €20 billion, and the timeline for operation at full power was moved from the original estimate of 2016 to 2025. The project however was significantly delayed at the design stage as result of purposeful decision to decentralize its design and manufacturing among 35 participating states, which resulted in complexity that was unprecedented but consistent with the initial ITER goals of creating knowledge and expertise rather than merely producing energy. As of 2009 the design of the main reactor was not yet finalized by the scientific team, which still introduced numerous modifications intended to optimize its operations, which was only finalized in 2017.[3]

A French association including about 700 anti-nuclear groups, Sortir du nucléaire (Get Out of Nuclear Energy), claimed that ITER was a hazard because scientists did not yet know how to manipulate the high-energy deuterium and tritium hydrogen isotopes used in the fusion process.[93] However, another French environmental association Association des Ecologistes Pour le Nucléaire (AEPN) welcomes the ITER project as an important part of response to climate change.[3]

Rebecca Harms, Green/EFA member of the European Parliament's Committee on Industry, Research and Energy, said: "In the next 50 years, nuclear fusion will neither tackle climate change nor guarantee the security of our energy supply." Arguing that the EU's energy research should be focused elsewhere, she said: "The Green/EFA group demands that these funds be spent instead on energy research that is relevant to the future. A major focus should now be put on renewable sources of energy." French Green party lawmaker Noël Mamère claims that more concrete efforts to fight present-day global warming will be neglected as a result of ITER: "This is not good news for the fight against the greenhouse effect because we're going to put ten billion euros towards a project that has a term of 30–50 years when we're not even sure it will be effective."[94][*dead link*]

Responses to criticism [edit]

Proponents believe that much of the ITER criticism is misleading and inaccurate, in particular the allegations of the experiment's "inherent danger". The stated goals for a commercial fusion power station design are that the amount of radioactive waste produced should be hundreds of times less than that of a fission reactor, and that it should produce no long-lived radioactive waste, and that it is impossible for any such reactor to undergo a large-scale runaway chain reaction.[95] A direct contact of the plasma with ITER inner walls would contaminate it, causing it to cool immediately and stop the fusion process. In addition, the amount of fuel contained in a fusion reactor chamber (one half gram of deuterium/tritium fuel[17]) is only sufficient to sustain the fusion burn pulse from minutes up to an hour at most, whereas a fission reactor usually contains several years' worth of fuel.[96] Moreover, some detritiation systems will be implemented, so that, at a fuel cycle inventory level of about 2 kg (4.4 lb), ITER will eventually need to recycle large amounts of tritium and at turnovers orders of magnitude higher than any preceding tritium facility worldwide.[97]

In the case of an accident (or sabotage), it is expected that a fusion reactor would release far less radioactive pollution than would an ordinary fission nuclear station. Furthermore, ITER's type of fusion power has little in common with nuclear weapons technology, and does not produce the fissile materials necessary for the construction of a weapon. Proponents note that large-scale fusion power would be able to produce reliable electricity on demand, and with virtually zero pollution (no gaseous CO_2, SO_2, or NO_x by-products are produced).

According to researchers at a demonstration reactor in Japan, a fusion generator should be feasible in the 2030s and no later than the 2050s. Japan is pursuing its own research program with several operational facilities that are exploring several fusion paths.[98]

In the United States alone, electricity accounts for US$210 billion in annual sales.[99] Asia's electricity sector attracted US$93 billion in private investment between 1990 and 1999.[100] These figures take into account only current prices. Proponents of

ITER contend that an investment in research now should be viewed as an attempt to earn a far greater future return.[citation needed] Also, worldwide investment of less than US$1 billion per year into ITER is not incompatible with concurrent research into other methods of power generation, which in 2007 totaled US$16.9 billion.[101] When asked about the growing cost of the ITER project an investment banker Daniel Allen argued, that for a technology that could "revolutionize the future", the budget of €20 billion or even €40 billion (the highest estimate) is "peanuts".[3]

Supporters of ITER emphasize that the only way to test ideas for withstanding the intense neutron flux is to experimentally subject materials to that flux, which is one of the primary missions of ITER and the IFMIF,[17] and both facilities will be vitally important to that effort.[102] The purpose of ITER is to explore the scientific and engineering questions that surround potential fusion power stations. It is nearly impossible to acquire satisfactory data for the properties of materials expected to be subject to an intense neutron flux, and burning plasmas are expected to have quite different properties from externally heated plasmas.[citation needed] Supporters contend that the answer to these questions requires the ITER experiment, especially in the light of the monumental potential benefits.

Furthermore, the main line of research via tokamaks has been developed to the point that it is now possible to undertake the penultimate step in magnetic confinement plasma physics research with a self-sustained reaction. In the tokamak research program, recent advances devoted to controlling the configuration of the plasma have led to the achievement of substantially improved energy and pressure confinement, which reduces the projected cost of electricity from such reactors by a factor of two to a value only about 50% more than the projected cost of electricity from advanced light-water reactors.[103] In addition, progress in the development of advanced, low activation structural materials supports the promise of environmentally benign fusion reactors and research into alternate confinement concepts is yielding the promise of future improvements in confinement.[103] Finally, supporters contend that other potential replacements to the fossil fuels have environmental issues of their own. Solar, wind, and hydroelectric power all have very low surface power density compared to ITER's successor DEMO which, at 2,000 MW, would have an energy density that exceeds even large fission power stations.[104]

Safety of the project is regulated according to French and EU nuclear power regulations. In 2011 French Environmental Authority (ASN) delivered favorable opinion and then based on French Act on Nuclear Transparency and Safety the licensing application was subject to public enquiry that allowed general public to submit requests for information regarding safety of the project. According to published safety assessments, approved by the ASN, in the worst case of reactor leak released radioactivity will not exceed 1/1000 of natural background radiation and no evacuation of local residents will be required. The whole installation includes a number of stress tests to confirm efficiency of all barriers. The whole reactor building is built on top of almost 500 seismic suspension columns and the whole complex is located almost 300 m above sea level. Overall, extremely rare events such as 100-year flood of nearby Durance river and 10,000-year earthquakes were assumed in the safety design of the complex and respective safeguards are part of the design.[3]

Between 2008 and 2017 the project has generated 34,000 job-years in the EU economy alone and it's estimated that in the 2018-2030 period it will generate further 74,000 job-years and €15.9 billion in gross value added.[3]

Similar projects [edit]

Precursors to ITER were EAST, SST-1, KSTAR, JET,[105] and Tore Supra.[106] Similar reactors include the Wendelstein 7-X.[107] Russia develops T-15MD tokamak in parallel with its participation in the ITER. Other planned and proposed fusion reactors include DEMO,[108] NIF,[109] HiPER,[110] and MAST,[111] SST-2[112] as well as CFETR (China Fusion Engineering Test Reactor), a 200 MW tokamak.[113][114][115][116]

See also [edit]

- Atoms for Peace (US Cold War-era science diplomacy strategy)
- Baruch Plan (post-War US attempt to internationalize fission)
- COLEX process (isotopic separation)
- EAST (Experimental Advanced Superconducting Tokamak)
- SST-1 (tokamak) (Steady State Superconducting Tokamak)
- Fusenet, European Fusion Education Network, 2008-2013
- Fusion for Energy, the Domestic Agency in charge of managing EU contributions to the ITER project
- International Fusion Materials Irradiation Facility, proposed, construction not started
- ITER Neutral Beam Test Facility, the facility dedicated to the development of the ITER neutral beam injector prototype
- JT-60, Japan's magnetic fusion program
- KSTAR (Korea Superconducting Tokamak Advanced Research), one of the first research tokamaks in the world to feature fully superconducting magnets
- National Ignition Facility, inertial confinement using lasers
- Nuclear power in France
- Science diplomacy
- Spherical Tokamak for Energy Production
- Wendelstein 7-X (German experimental fusion reactor) - a stellarator

Nuclear technology portal
Energy portal
Science portal
France portal

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